

ABSOLUTE C++

SIXTH EDITION



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Chapter 10

Pointers and Dynamic Arrays

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Learning Objectives

- Pointers
 - Pointer variables
 - Memory management
- Dynamic Arrays
 - Creating and using
 - Pointer arithmetic
- Classes, Pointers, Dynamic Arrays
 - The *this* pointer
 - Destructors, copy constructors

Pointer Introduction

- Pointer definition:
 - Memory address of a variable
- Recall: memory divided
 - Numbered memory locations
 - Addresses used as name for variable
- You've used pointers already!
 - Call-by-reference parameters
 - Address of actual argument was passed

Pointer Variables

- Pointers are "typed"
 - Can store pointer in variable
 - Not int, double, etc.
 - Instead: A POINTER to int, double, etc.!
- Example:
`double *p;`
 - p is declared a "pointer to double" variable
 - Can hold pointers to variables of type double
 - Not other types! (unless typecast, but could be dangerous)

Declaring Pointer Variables

- Pointers declared like other types
 - Add "*" before variable name
 - Produces "pointer to" that type
- "*" must be before each variable
- `int *p1, *p2, v1, v2;`
 - p1, p2 hold pointers to int variables
 - v1, v2 are ordinary int variables

Addresses and Numbers

- Pointer is an address
- Address is an integer
- Pointer is NOT an integer!
 - Not crazy → abstraction!
- C++ forces pointers be used as addresses
 - Cannot be used as numbers
 - Even though it "is a" number

Pointing

- Terminology, view
 - Talk of "pointing", not "addresses"
 - Pointer variable "points to" ordinary variable
 - Leave "address" talk out
- Makes visualization clearer
 - "See" memory references
 - Arrows

Pointing to ...

- `int *p1, *p2, v1, v2;`
`p1 = &v1;`
 - Sets pointer variable `p1` to "point to" int variable `v1`
- Operator, `&`
 - Determines "address of" variable
- Read like:
 - "`p1` gets address of `v1`"
 - Or "`p1` points to `v1`"

Pointing to ...

- Recall:
`int *p1, *p2, v1, v2;`
`p1 = &v1;`
- Two ways to refer to v1 now:
 - Variable v1 itself:
`cout << v1;`
 - Via pointer p1:
`cout *p1;`
- Dereference operator, `*`
 - Pointer variable "dereferenced"
 - Means: "Get data that p1 points to"

"Pointing to" Example

- Consider:
v1 = 0;
p1 = &v1;
*p1 = 42;
cout << v1 << endl;
cout << *p1 << endl;
- Produces output:
42
42
- p1 and v1 refer to same variable

& Operator

- The "address of" operator
- Also used to specify call-by-reference parameter
 - No coincidence!
 - Recall: call-by-reference parameters pass "address of" the actual argument
- Operator's two uses are closely related

Pointer Assignments

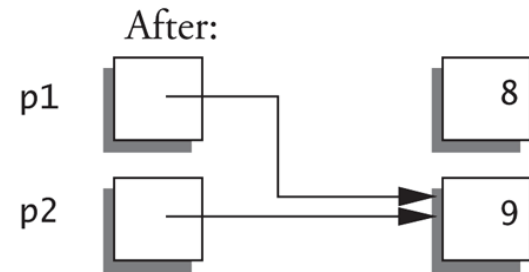
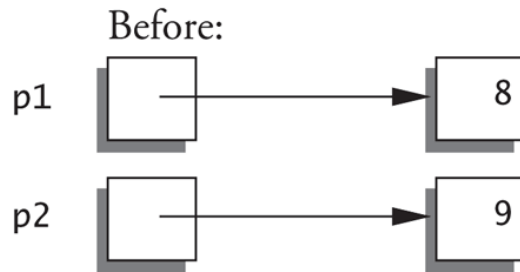
- Pointer variables can be "assigned":
`int *p1, *p2;`
`p2 = p1;`
 - Assigns one pointer to another
 - "Make p2 point to where p1 points"
- Do not confuse with:
`*p1 = *p2;`
 - Assigns "value pointed to" by p1, to "value pointed to" by p2

Pointer Assignments Graphic:

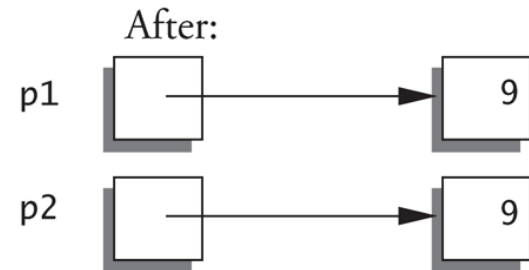
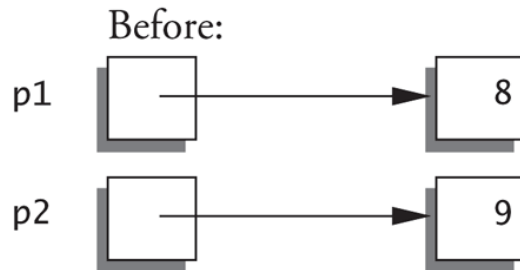
Display 10.1 Uses of the Assignment Operator with Pointer Variables

Display 10.1 Uses of the Assignment Operator with Pointer Variables

`p1 = p2;`



`*p1 = *p2;`



The new Operator

- Since pointers can refer to variables...
 - No "real" need to have a standard identifier
- Can dynamically allocate variables
 - Operator *new* creates variables
 - No identifiers to refer to them
 - Just a pointer!
- `p1 = new int;`
 - Creates new "nameless" variable, and assigns p1 to "point to" it
 - Can access with `*p1`
 - Use just like ordinary variable

Basic Pointer Manipulations Example:

Display 10.2 Basic Pointer Manipulations (1 of 2)

Display 10.2 Basic Pointer Manipulations

```
1  //Program to demonstrate pointers and dynamic variables.
2  #include <iostream>
3  using std::cout;
4  using std::endl;

5  int main( )
6  {
7      int *p1, *p2;

8      p1 = new int;
9      *p1 = 42;
10     p2 = p1;
11     cout << "*p1 == " << *p1 << endl;
12     cout << "*p2 == " << *p2 << endl;

13     *p2 = 53;
14     cout << "*p1 == " << *p1 << endl;
15     cout << "*p2 == " << *p2 << endl;
```

Basic Pointer Manipulations Example:

Display 10.2 Basic Pointer Manipulations (2 of 2)

```
16     p1 = new int;  
17     *p1 = 88;  
18     cout << "*p1 == " << *p1 << endl;  
19     cout << "*p2 == " << *p2 << endl;  
  
20     cout << "Hope you got the point of this example!\n";  
21     return 0;  
22 }
```

SAMPLE DIALOGUE

```
*p1 == 42  
*p2 == 42  
*p1 == 53  
*p2 == 53  
*p1 == 88  
*p2 == 53  
Hope you got the point of this example!
```

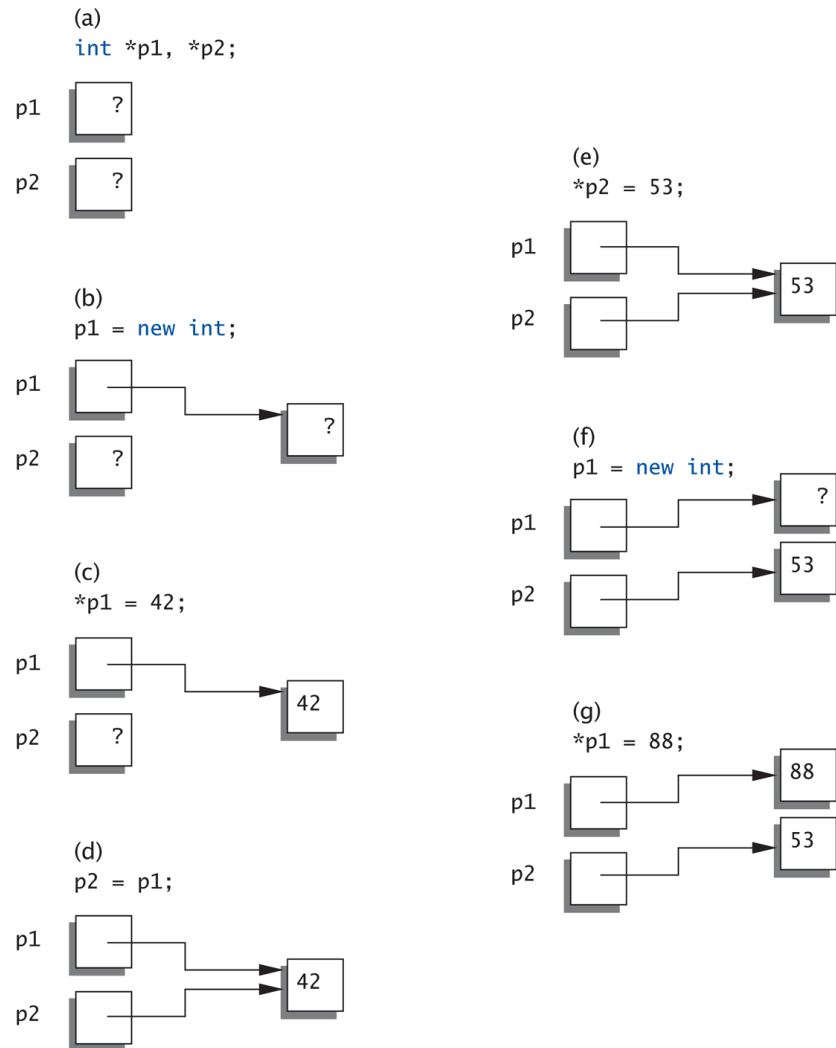

Basic Pointer Manipulations

Graphic:

Display 10.3

Explanation of Display 10.2

Display 10.3 Explanation of Display 10.2



More on new Operator

- Creates new dynamic variable
- Returns pointer to the new variable
- If type is class type:
 - Constructor is called for new object
 - Can invoke different constructor with initializer arguments:
`MyClass *mcPtr;`
`mcPtr = new MyClass(32.0, 17);`
- Can still initialize non-class types:
`int *n;`
`n = new int(17); //Initializes *n to 17`

Pointers and Functions

- Pointers are full-fledged types
 - Can be used just like other types
- Can be function parameters
- Can be returned from functions
- Example:
`int* findOtherPointer(int* p);`
 - This function declaration:
 - Has "pointer to an int" parameter
 - Returns "pointer to an int" variable

Memory Management

- Heap
 - Also called "freestore"
 - Reserved for dynamically-allocated variables
 - All new dynamic variables consume memory in freestore
 - If too many → could use all freestore memory
- Future "new" operations will fail if freestore is "full"

C++11 nullptr

- NULL is actually the number 0 and can lead to ambiguity

```
void func(int *p);  
void func(int i);
```

- Which func is invoked given **func(NULL)**? Both are equally valid since NULL is 0
- C++11 resolves this problem by introducing a new constant, **nullptr**
- **nullptr** is not 0
- Can use anywhere you could use NULL

Checking new Success

- Older compilers:
 - Test if null returned by call to *new*:

```
int *p;  
p = new int;  
if (p == nullptr) // NULL represents empty pointer  
{  
    cout << "Error: Insufficient memory.\n";  
    exit(1);  
}
```
 - If new succeeded, program continues

new Success – New Compiler

- Newer compilers:
 - If new operation fails:
 - Program terminates automatically
 - Produces error message
- Still good practice to use nullptr check
- NULL represents the empty pointer or a pointer to nothing and will be used later to mark the end of a list

C++11 nullptr

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```
void func(int *p);  
void func(int i);
```

- Which func is invoked given **func(NULL)**? Both are equally valid since NULL is 0
- C++11 resolves this problem by introducing a new constant, **nullptr**
- **nullptr** is not 0
- Can use anywhere you could use NULL

Freestore Size

- Varies with implementations
- Typically large
 - Most programs won't use all memory
- Memory management
 - Still good practice
 - Solid software engineering principle
 - Memory IS finite
 - Regardless of how much there is!

delete Operator

- De-allocate dynamic memory
 - When no longer needed
 - Returns memory to freestore
 - Example:

```
int *p;  
p = new int(5);  
... //Some processing...  
delete p;
```
 - De-allocates dynamic memory "pointed to by pointer p"
 - Literally "destroys" memory

Dangling Pointers

- delete p;
 - Destroys dynamic memory
 - But p still points there!
 - Called "dangling pointer"
 - If p is then dereferenced (*p)
 - Unpredictable results!
 - Often disastrous!
- Avoid dangling pointers
 - Assign pointer to NULL after delete:
delete p;
p = nullptr;

Dynamic and Automatic Variables

- Dynamic variables
 - Created with new operator
 - Created and destroyed while program runs
- Local variables
 - Declared within function definition
 - Not dynamic
 - Created when function is called
 - Destroyed when function call completes
 - Often called "automatic" variables
 - Properties controlled for you

Define Pointer Types

- Can "name" pointer types
- To be able to declare pointers like other variables
 - Eliminate need for "*" in pointer declaration
- `typedef int* IntPtr;`
 - Defines a "new type" alias
 - Consider these declarations:
`IntPtr p;`
`int *p;`
 - The two are equivalent

Pitfall: Call-by-value Pointers

- Behavior subtle and troublesome
 - If function changes pointer parameter itself → only change is to local copy
- Best illustrated with example...

Call-by-value Pointers Example:

Display 10.4 A Call-by-Value Pointer Parameter (1 of 2)

Display 10.4 A Call-by-Value Pointer Parameter

```
1  //Program to demonstrate the way call-by-value parameters
2  //behave with pointer arguments.
3  #include <iostream>
4  using std::cout;
5  using std::cin;
6  using std::endl;

7  typedef int* IntPtr;

8  void sneaky(IntPtr temp);

9  int main( )
10 {
11     IntPtr p;

12     p = new int;
13     *p = 77;
14     cout << "Before call to function *p == "
15          << *p << endl;
```

Call-by-value Pointers Example:

Display 10.4 A Call-by-Value Pointer Parameter (2 of 2)

```
16     sneaky(p);

17     cout << "After call to function *p == "
18           << *p << endl;

19     return 0;
20 }
21 void sneaky(IntPointer temp)
22 {
23     *temp = 99;
24     cout << "Inside function call *temp == "
25           << *temp << endl;
26 }
```

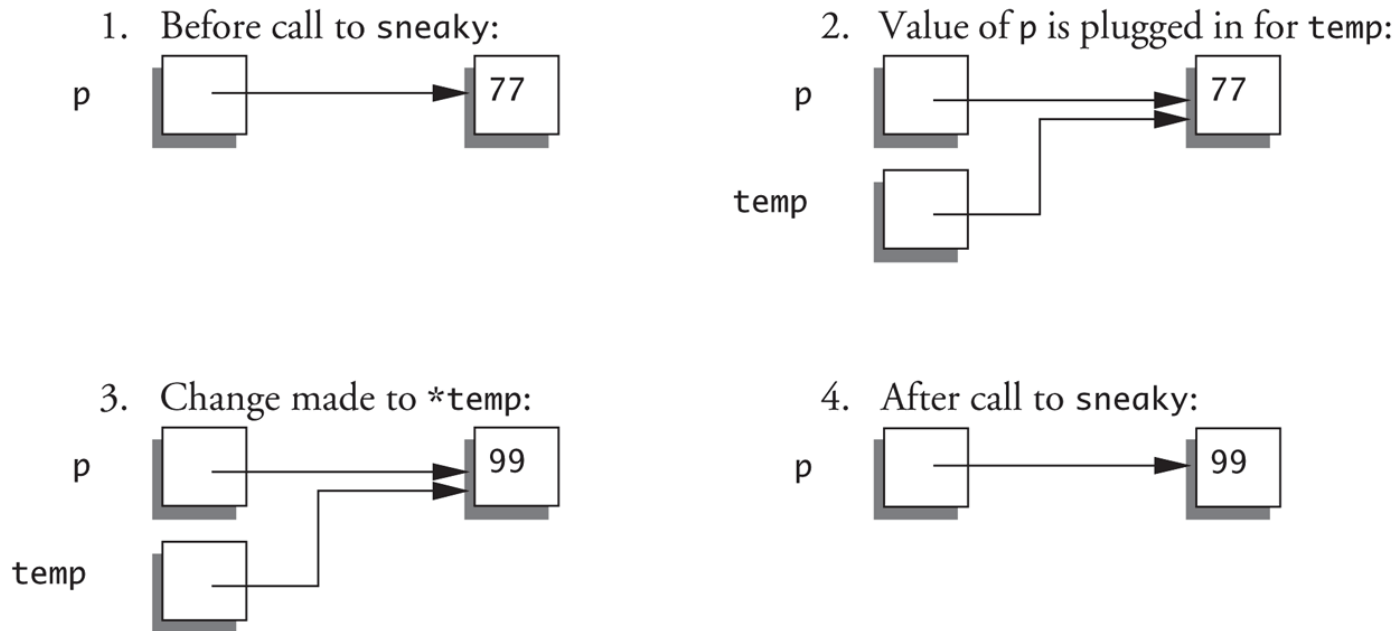
SAMPLE DIALOGUE

Before call to function *p == 77
Inside function call *temp == 99
After call to function *p == 99

Call-by-value Pointers Graphic:

Display 10.5 The Function Call sneaky(p);

Display 10.5 The Function Call `sneaky(p)` ;



Dynamic Arrays

- Array variables
 - Really pointer variables!
- Standard array
 - Fixed size
- Dynamic array
 - Size not specified at programming time
 - Determined while program running

Array Variables

- Recall: arrays stored in memory addresses, sequentially
 - Array variable "refers to" first indexed variable
 - So array variable is a kind of pointer variable!
- Example:
`int a[10];`
`int * p;`
 - a and p are both pointer variables!

Array Variables → Pointers

- Recall previous example:

```
int a[10];  
typedef int* IntPtr;  
IntPtr p;
```
- a and p are pointer variables
 - Can perform assignments:

```
p = a; // Legal.
```

 - p now points where a points
 - To first indexed variable of array a
 - ```
a = p; // ILLEGAL!
```

    - Array pointer is CONSTANT pointer!

# Array Variables → Pointers

- Array variable  
`int a[10];`
- MORE than a pointer variable
  - "int \* const" type
  - Array was allocated in memory already
  - Variable *a* MUST point there...always!
    - Cannot be changed!
- In contrast to ordinary pointers
  - Which can (& typically do) change

# Dynamic Arrays

- Array limitations
  - Must specify size first
  - May not know until program runs!
- Must "estimate" maximum size needed
  - Sometimes OK, sometimes not
  - "Wastes" memory
- Dynamic arrays
  - Can grow and shrink as needed

# Creating Dynamic Arrays

- Very simple!
- Use new operator
  - Dynamically allocate with pointer variable
  - Treat like standard arrays
- Example:

```
typedef double * DoublePtr;
DoublePtr d;
d = new double[10]; //Size in brackets
```

  - Creates dynamically allocated array variable *d*, with ten elements, base type double

# Deleting Dynamic Arrays

- Allocated dynamically at run-time
  - So should be destroyed at run-time
- Simple again. Recall Example:  
d = new double[10];  
... //Processing  
delete [] d;
  - De-allocates all memory for dynamic array
  - Brackets indicate "array" is there
  - Recall: *d* still points there!
    - Should set d = NULL;



# Function that Returns an Array

- Array type NOT allowed as return-type of function
- Example:  
`int [] someFunction(); // ILLEGAL!`
- Instead return pointer to array base type:  
`int* someFunction(); // LEGAL!`

# Pointer Arithmetic

- Can perform arithmetic on pointers
  - "Address" arithmetic

- Example:

```
typedef double* DoublePtr;
```

```
DoublePtr d;
```

```
d = new double[10];
```

- d contains address of d[0]
- d + 1 evaluates to address of d[1]
- d + 2 evaluates to address of d[2]
  - Equates to "address" at these locations

# Alternative Array Manipulation

- Use pointer arithmetic!
- "Step thru" array without indexing:  
for (int i = 0; i < arraySize; i++)  
    cout << \*(d + i) << " ";
- Equivalent to:  
for (int i = 0; i < arraySize; i++)  
    cout << d[i] << " ";
- Only addition/subtraction on pointers
  - No multiplication, division
- Can use ++ and -- on pointers

# Multidimensional Dynamic Arrays

- Yes we can!
- Recall: "arrays of arrays"
- Type definitions help "see it":

```
typedef int* IntArrayPtr;
IntArrayPtr *m = new IntArrayPtr[3];
```

  - Creates array of three pointers
  - Make each allocate array of 4 ints
- ```
for (int i = 0; i < 3; i++)  
    m[i] = new int[4];
```

 - Results in three-by-four dynamic array!

Back to Classes

- The -> operator
 - Shorthand notation
- Combines dereference operator, *, and dot operator
- Specifies member of class "pointed to" by given pointer
- Example:
MyClass *p;
p = new MyClass;
p->grade = "A"; Equivalent to:
(*p).grade = "A";

The this Pointer

- Member function definitions might need to refer to calling object
- Use predefined *this* pointer
 - Automatically points to calling object:
Class Simple
{
public:
 void showStuff() const;
private:
 int stuff;
};
- Two ways for member functions to access:
cout << stuff;
cout << this->stuff;

Overloading Assignment Operator

- Assignment operator returns reference
 - So assignment "chains" are possible
 - e.g., `a = b = c;`
 - Sets `a` and `b` equal to `c`
- Operator must return "same type" as it's left-hand side
 - To allow chains to work
 - The *this* pointer will help with this!

Overloading Assignment Operator

- Recall: Assignment operator must be member of the class
 - It has one parameter
 - Left-operand is calling object
`s1 = s2;`
 - Think of like: `s1.=(s2);`
- `s1 = s2 = s3;`
 - Requires `(s1 = s2) = s3;`
 - So `(s1 = s2)` must return object of `s1`'s type
 - And pass to `" = s3";`

Overloaded = Operator Definition

- Uses string Class example:

```
StringClass& StringClass::operator=(const StringClass& rtSide)
{
    if (this == &rtSide)           // if right side same as left side
        return *this;
    else
    {
        capacity = rtSide.length;
        length
        length = rtSide.length;
        delete [] a;
        a = new char[capacity];
        for (int l = 0; l < length; l++)
            a[l] = rtSide.a[l];
        return *this;
    }
}
```

Shallow and Deep Copies

- Shallow copy
 - Assignment copies only member variable contents over
 - Default assignment and copy constructors
- Deep copy
 - Pointers, dynamic memory involved
 - Must dereference pointer variables to "get to" data for copying
 - Write your own assignment overload and copy constructor in this case!

Destructor Need

- Dynamically-allocated variables
 - Do not go away until "deleted"
- If pointers are only private member data
 - They dynamically allocate "real" data
 - In constructor
 - Must have means to "deallocate" when object is destroyed
- Answer: destructor!

Destructors

- Opposite of constructor
 - Automatically called when object is out-of-scope
 - Default version only removes ordinary variables, not dynamic variables
- Defined like constructor, just add ~
 - `MyClass::~~MyClass()`
 {
 //Perform delete clean-up duties
 }

Copy Constructors

- Automatically called when:
 1. Class object declared and initialized to other object
 2. When function returns class type object
 3. When argument of class type is "plugged in" as actual argument to call-by-value parameter
- Requires "temporary copy" of object
 - Copy constructor creates it
- Default copy constructor
 - Like default "=", performs member-wise copy
- Pointers → write own copy constructor!

Summary 1

- Pointer is memory address
 - Provides indirect reference to variable
- Dynamic variables
 - Created and destroyed while program runs
- Freestore
 - Memory storage for dynamic variables
- Dynamically allocated arrays
 - Size determined as program runs

Summary 2

- Class destructor
 - Special member function
 - Automatically destroys objects
- Copy constructor
 - Single argument member function
 - Called automatically when temp copy needed
- Assignment operator
 - Must be overloaded as member function
 - Returns reference for chaining